Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

Assembly of Dissimilar Aluminum Alloys for Automotive Applications

Piyush Upadhyay
Tim Roosendaal
Li Xiao

Eric Boettcher, Honda R&D Americas Inc.
Russell Long, Arconic Inc.

Pacific Northwest National Laboratory

Project ID # mat134

VTO/DOE Annual Merit Review Meeting, June 12, 2019

Project Overview

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

Project Timeline

- Start: Q4 FY2017
- Finish: Q4 FY2019
- 80% Complete

Barriers

- Joining method that can meet crash requirements at high volume manufacturing rate with low cost is lacking[1].
- Increased joining speed is needed for process commercialization.

1.Light Duty workshop final report (2013)

Budget

- Total project funding: $1M
  - DOE: $500k
  - Industrial cost share: $500
- FY 18: $500k
- FY 19: $500k

Partners

- **Lead**
  PNNL
- **OEM**
  Honda R&D Americas, Inc.
- **Supplier**
  Arconic, Inc.

Pacific Northwest NATIONAL LABORATORY

HONDA
Honda R&D Americas, Inc.

ARCONIC
innovation, engineered.

Relevance

- **Overall Objective:**

  Develop joining technology needed to demonstrate fabrication of Aluminum alloy assemblies to enable automotive lightweighting for high volume industrial commercialization. (addressing technology gap identified by USDRIVE Roadmap (Sec. 5.3) 2017)

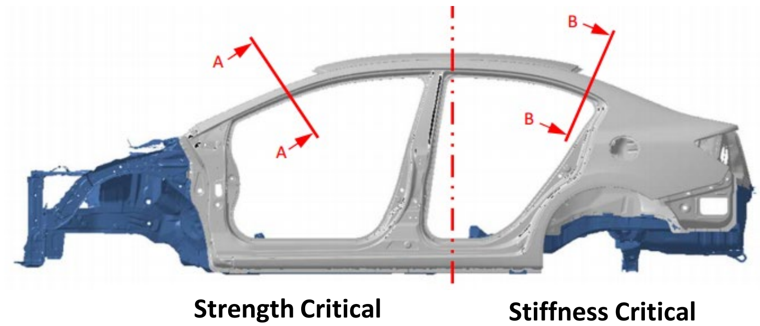
- **Objective (FY 2018-FY2019)**
  - Develop process parameters for joining 3 sheet configuration.
  - Establish and begin implementation of joint evaluation methods including peel and cross tension testing.

- **Impact**
  - Joining technology developed and transferred in this project will enable automotive lightweighting.
  - By increasing the welding speed up to industrial viability, we are maturing a laboratory developed solid phase processing technology for commercialization.

Relevance: Target application

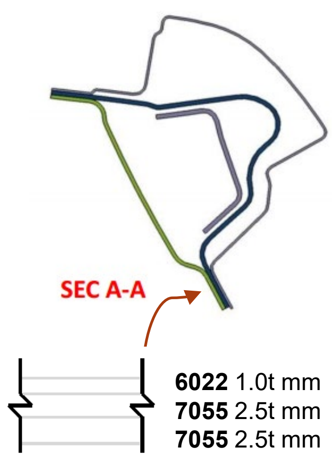
Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle *Since 1965*

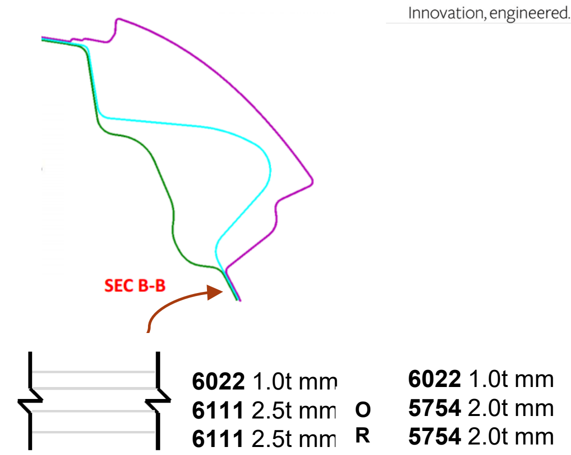
Future Sedan Structure
(Aluminum Cabin on a Steel Platform)



HONDA
Honda R&D Americas, Inc.

ARCONIC
Innovation, engineered.





The target is to integrate stamped Al alloys within the existing body construction, so that a function specific Al assembly can be tailored based on specific property needs.

Schedule and Progress

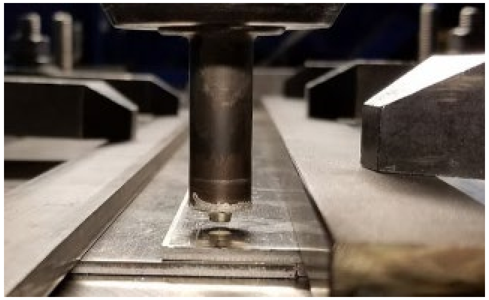
Pacific Northwest NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

		FY-17	FY2018				FY2019		
	Quarter	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**
	1.1. Material configurations & combinations								
FY18	**Milestone 1**		*						
FY18	1.2. Weld development								
	1.3. Baseline Joint characterization								
	Milestone 2					*			
FY18	1.4 Near trim edge weld line sensitivity study								
	1.5 Analysis of process factors and outcomes:								
	Milestone 3						*		
	Decision Gate: Joint Performance								
	2.1 Extended material combinations								
	2.2. FSLW tool optimization								
FY19	3.1 Prototype design								
On track	**Milestone 4**							*	
	3.2. Technology Transfer								

Project Milestones

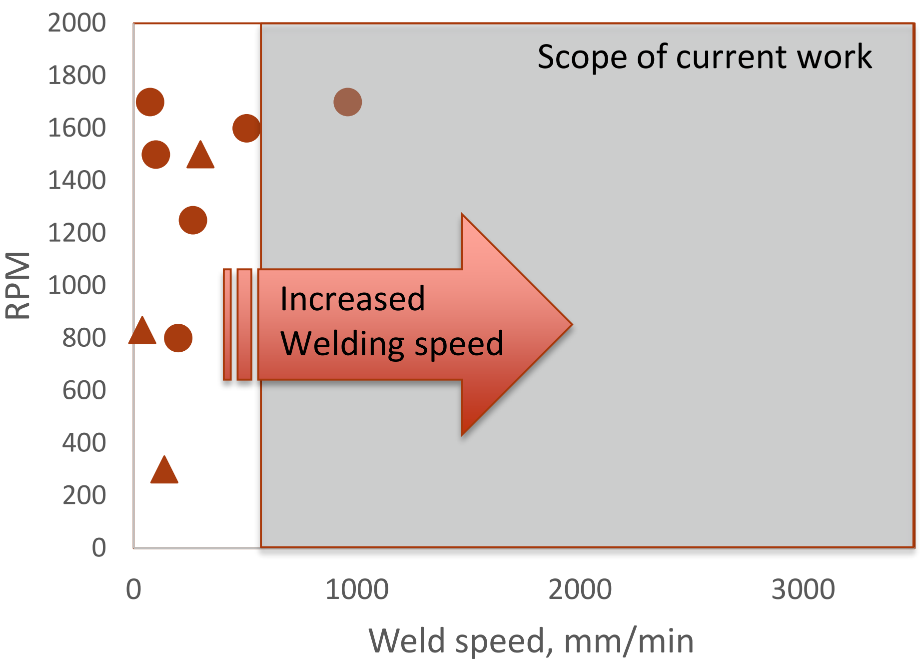
- **Milestone 1 (Q2):** Material combinations and configurations are finalized. Testing requirements are finalized for joint assessment for the remainder of the project. (Complete)
- **Milestone 2 (Q5):** Welding parameters are down selected on the basis of testing matrix established in Milestone 1, such that effective joints are obtained with welding speed greater than 1.0m/min. (Complete)
- **Milestone 3 (Q6):** Sensitivity study for weld line near the trim edge is complete.(Complete)
- **Milestone 4 (Q7):** Prototype design is complete. FSLW tool optimization for joints developed in the project is complete. (on-track)

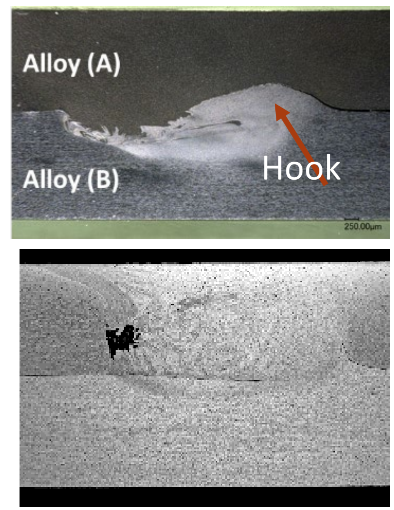


Approach: High speed FSLW

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*

The project utilizes friction stir lap welding (FSLW) method at high speed (welding speed ≥500mm/min) for Al alloys assembly.





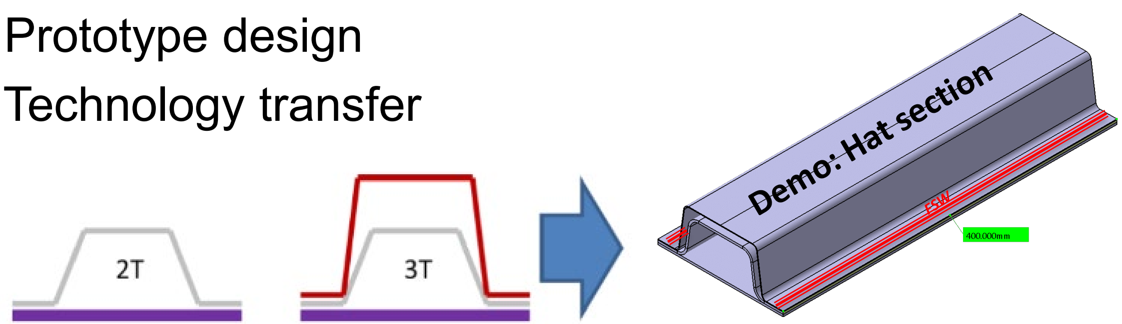
Issues with joining multiples sheets

Hooks
Sheet thinning
Inadequate oxide mixing.
Worm Hole defect
7xxx series
- Incipient melting
- Tool forces/mixing

The approach is to establish welding parameters that can minimize interface hooking (upturn) and eliminate weld defect at high speed for 2 sheet and 3 sheet joining.

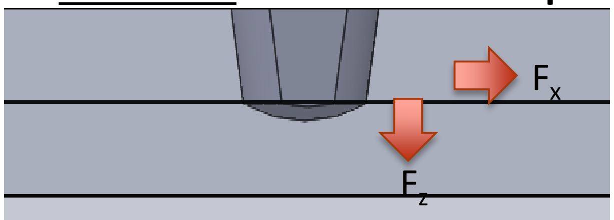
Technical Approach: Task Flow

- <u>Task 1</u>: Material Stack-up and Baseline development
  - Task 1.1.Materials and Configurations
  - Task 1.2.Weld development
  - Task 1.3 Baseline Characterization
- <u>Task 2</u>: Extended weld development & interface characterization
  - Task 2.1 Material variations
  - Task 2.2 FSLW tool Optimization (Design of Experiments approach)
  - Task 2.3 Comprehensive Weld assessment.
- <u>Task 3</u>: Prototype development and demonstration
  - Task 3.1 Prototype design
  - Task 3.2 Technology transfer



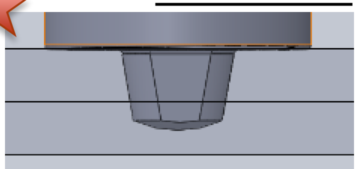
Approach:
Three sheet welding configurations

Method A: Thin sheet on top



Pros: Single step.
Cons : Thin sheet residual stresses, chances of sheet tearing, Needs longer pin, greater F_x than Method 2.

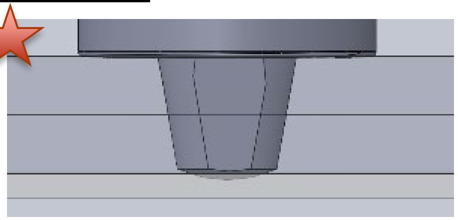
Method B: Two step approach


Step 1


Step 2

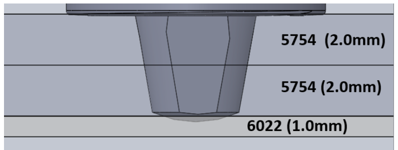
Pros: Shorter pin, simple setting up
Cons : Two steps, two tools

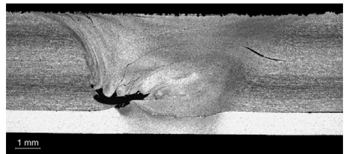
Method C: Thick sheet on top



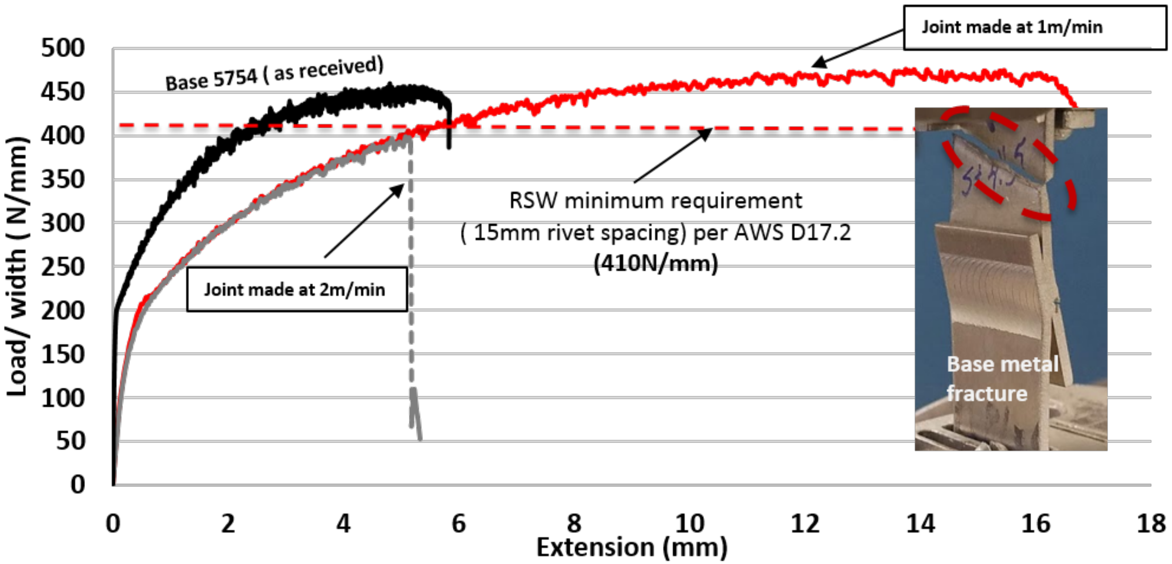
Pros: Single Step, no surface changes on the thin outer layer.
Cons : Considerably long Pin, Largest F_x, Two thick sheets disturbed by the pin completely.

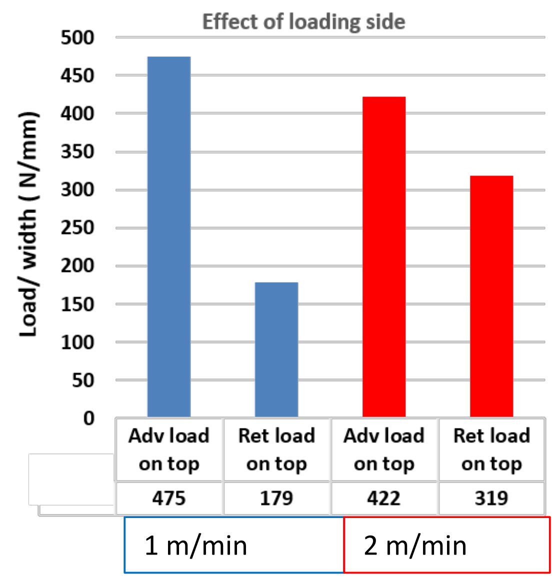
Accomplishments
Lap shear testing (5754-5754-6022)





Joint cross-section

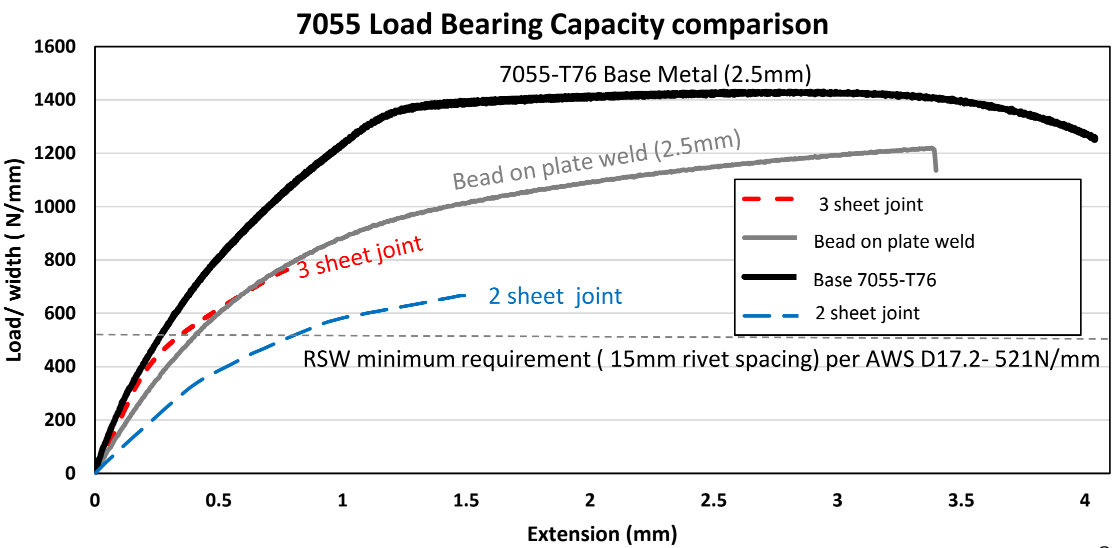


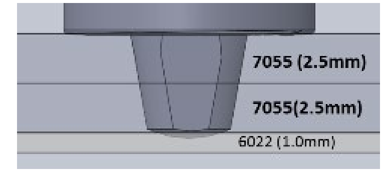


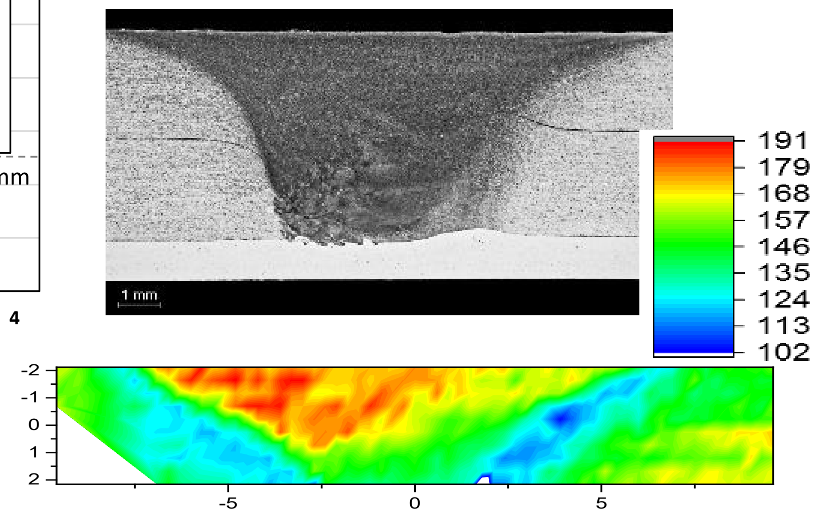
- Demonstrated welding speed of 2m/min in 3 sheet joint configuration.
- Despite a worm hole defect, lap test samples fractured in base metal.
- We observed load bearing capacity of 80-100% of base metal on adv. side loaded on top samples.

Accomplishments
Lap shear testing (7055-7055-6022)

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*





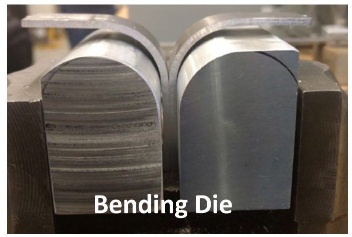


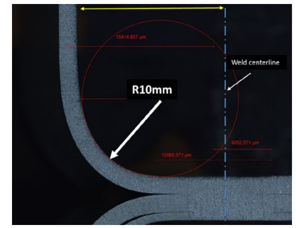
Micro hardness distribution

This year we demonstrated 3 sheet joining (7055-7055-6022) at a welding speed of <u>1m/min</u>. The lap shear strength corresponds to <u>53%</u> of base material load bearing capacity achieving the set project target.

Accomplishments: Coach peel tests

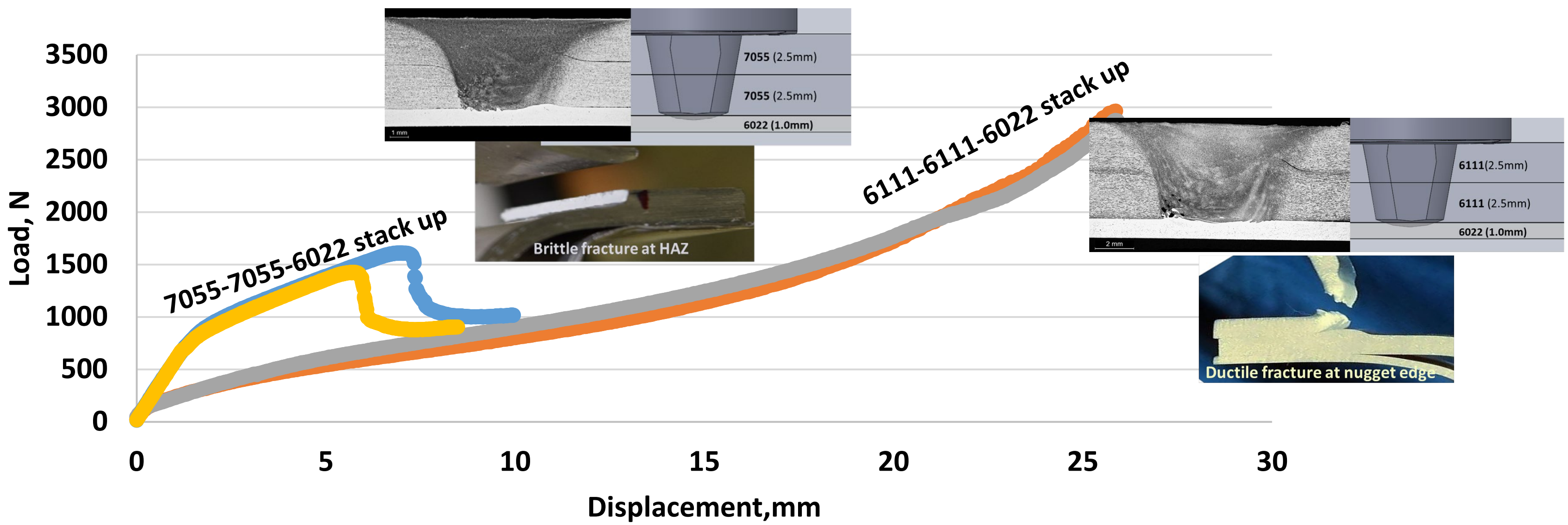
Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*





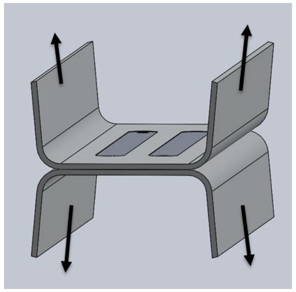
Post weld bending challenges

- ❑ Sample to sample inconsistency
- ❑ Opening of weld seam prior to test.

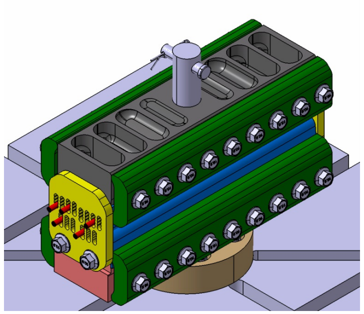


- Coach peel testing has allowed to optimize welds for peel configuration.
- Retreating side loaded joints performed better than advancing side loaded samples.
- Consistency of post weld bending of samples is problematic.

Accomplishments:
KSII sample fabrication and testing



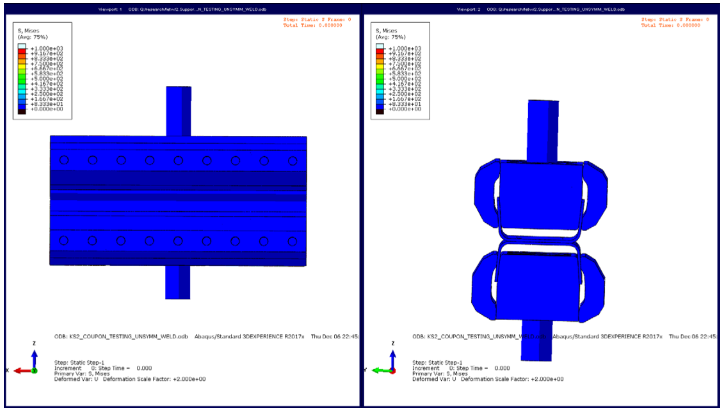
KSII sample



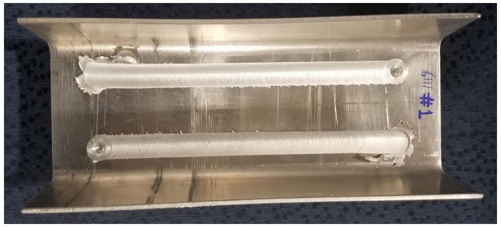
KSII test fixture design

KSII welding fixture

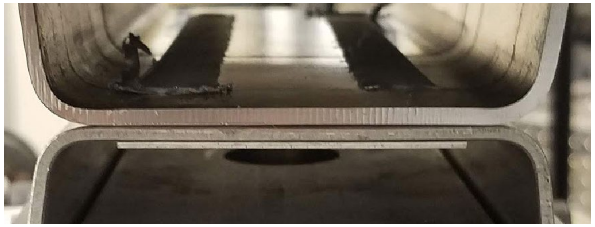
KSII test fixture



FEA modeling example shows effect of weld asymmetry
(currently assumes perfect bonding)



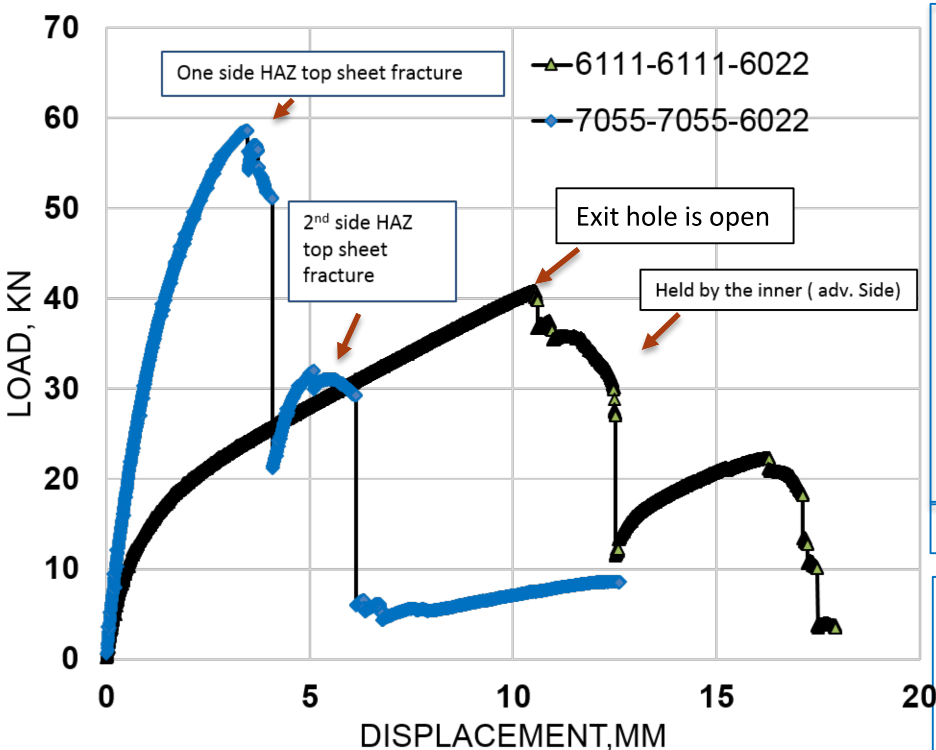
KSII sample top view



KSII sample side view

- KSII sample was used to test axial joint strength.
- KSII test also enabled load conditions not covered by lap shear and T-peel.
- HRA team lead the design of test fixture and provided modeling insight.

Accomplishments: KSII joint performance



7055-7055-6022 fractured sample

- Mostly HAZ fracture of top sheet
- Interfacial fracture near exit hole
- Max load = 370N/mm

6111-6111-6022 fractured sample

- Combination of HAZ fracture of bottom sheet and interfacial fracture
- Greater ductility
- Max load = 266 N/mm

Initial test results from KSII samples are promising.
Fracture mode was a combination of both fracture at the edge of the weld (HAZ) and interfacial.

Response to reviewer comments

- Reviewer: Good approach, consider a Future robotic application.
  - Response: Current project is being carried out in a gantry type machine to demonstrate joint viability at higher welding speed. We are implementing a few aspects that could be well suited for robotic application including limited clamping and fixturing, reduced weld distance from trim edge. Additionally, the planar forces and torque required for different welding parameters and alloys types and configurations are tracked for ease in robotic implementation.
- Reviewer: Comparison to baseline metal is not convincing and should be addressed by comparing it with other joining methods. Does it make sense to use as “baseline” the bead on plate weld rather than base metal as is currently done.
  - Minimum shear load requirement for RSW lap joints in shear loading (ref: AWS D17.2) has been added as a benchmark for lap shear data presented in Slides 10 and 11 above.
- Reviewer: What is the effect of welding more than half the thickness of the middle layer? This approach is not discussed?
  - 3 sheet welding, (Method C in slide 9) performed this year allowed us to investigate this questions. We went all the way into 2nd sheet in this approach. We did not see significant hook upturn compared to lesser engagement into the 2nd sheet. Additionally lap shear results are superior in some cases.

Collaboration and coordination

HONDA
Honda R&D Americas, Inc.

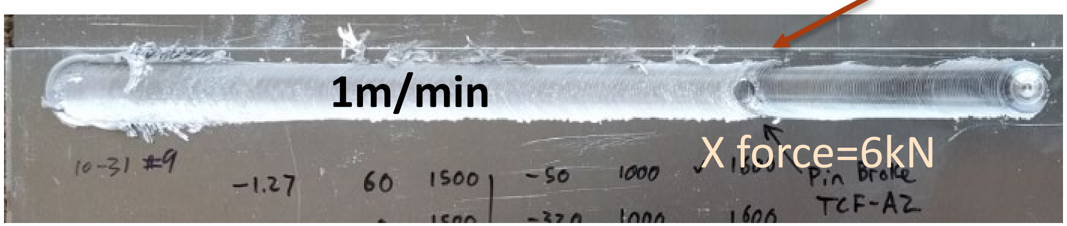
ARCONIC
Innovation, engineered.

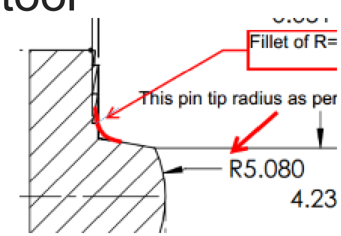
- We have regular conference calls and occasional on site meetings between partners where project work scope and tasks are discussed.
- Through the in-kind funds available to partners
  - Honda
    - Provides assessments on production relevance of material stack up and configurations
    - Provides input on joint evaluation/ characterization matrix and test requirements.
    - Leads on prototype design and evaluation metric and testing.
    - provides modeling support for design of weld and test fixtures.
  - Arconic
    - Provides relevant Aluminum alloys

Remaining Challenges and Barriers

- Performance of welds in shaped forms (hat sections, complex loading conditions are not well understood).
- Joining demonstration with limited clamping to demonstrate industrial viability.
- Increased welding speed (beyond 1m/min) for 7xxx is challenging.
  - Currently at greater welding speeds, we observe advancing side worm whole defects, and crown surface defects.
  - Larger welding speeds also results in significant forces in the tool leading to tool breaks.

Tool pin fracture near thread start.



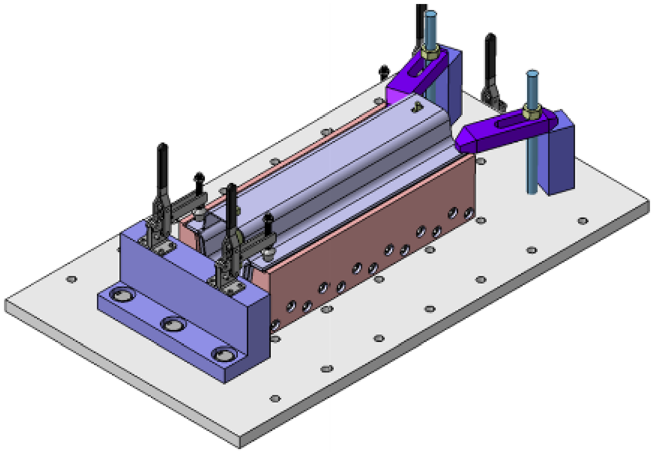


<u>Solution</u>

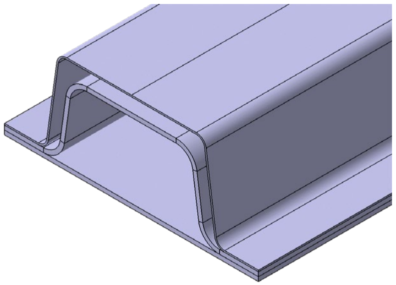
Increased fillet at pin root.
Reduced pin angle.

Planned future work

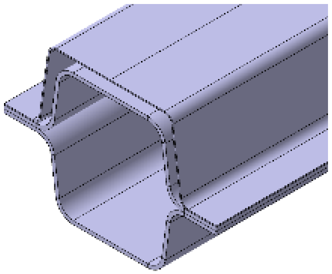
- Perform coupon level work with MP159 FSW tools with design targeted to withhold larger tool forces.
- Complete KSII weld fabrication and testing for different material combinations.
- Fabricate hat section welds for 3 point bend and crush testing and evaluation at HRA.



Fixture for hat section



3 point bend test



Axial crush test

Any proposed future work is subject to change based on funding levels.

Project Summary

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

The goal of this project is to develop FSLW such that viable joints in several Al alloys can be made at industrially viable welding speed for commercialization.

- This project develops an emerging solid state joining technique with potential to fabricate Al assembly such that
  - Cost of Al alloys joining can be reduced enabling vehicle light weighting.
  - Faster assembly process can enable adoption of newer Al alloy in high volume cars

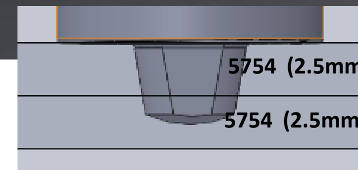
Key Technical Challenges	Accomplishments this year Results/Impact
Demonstrate joint Efficiency of 50% for FSLW.	We have exceeded the 50% joint efficiency requirements for all 3 material set for 3 sheet configuration.
Demonstrate high welding speed for industrial viability	For 3 sheet joints welds made at 2m/min welding speed for 6111 and 5754 material combination. And 1m/min for 7055 configuration

Deliverables coming up and Future work
Complete KSII evaluations for 3 material sets.
Complete Demo/hat section fabrication and testing.

Any proposed future work is subject to change based on funding levels.

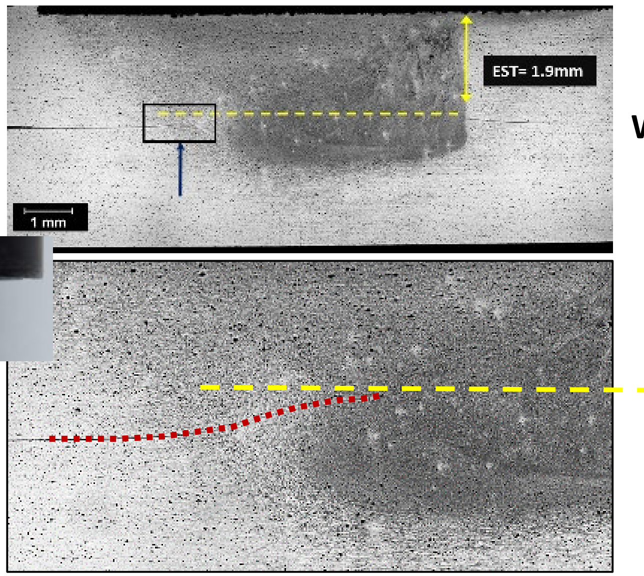
Backup slides

Hook size effects on lap shear test (5754)

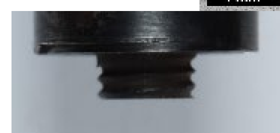


Welding speed: 1m/min

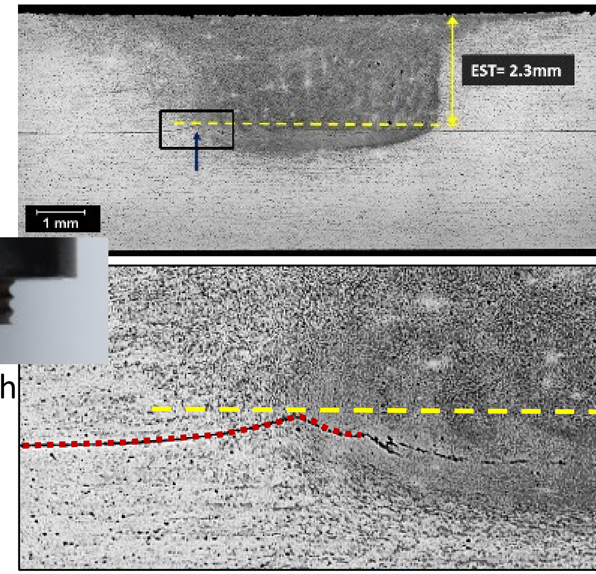
Pin length
3.4mm



Load bearing capacity**: 466±15N/mm**



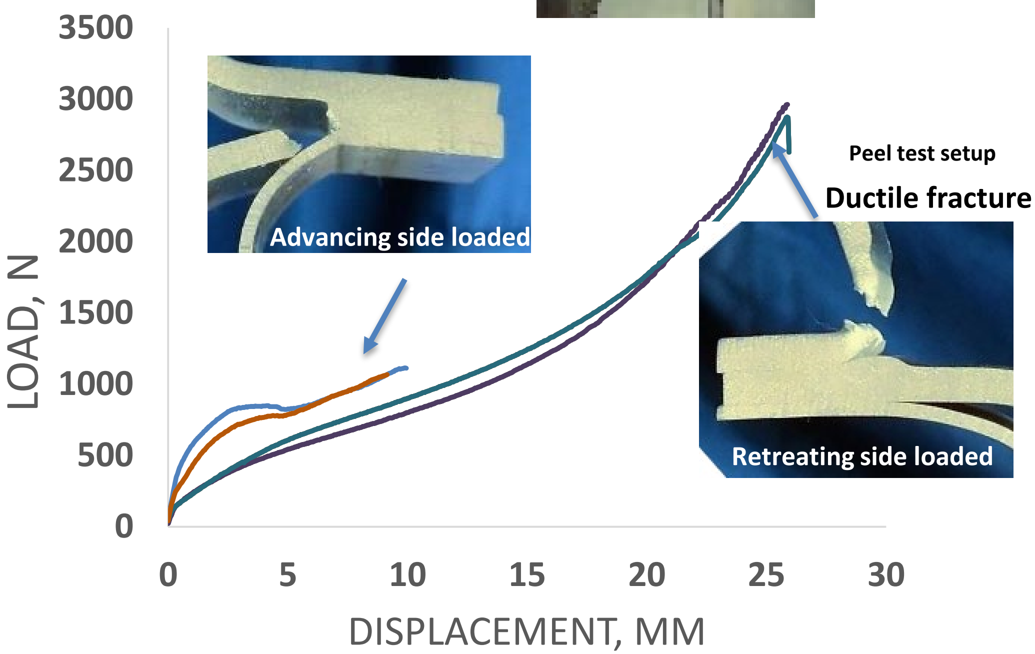
Pin length
3.1mm

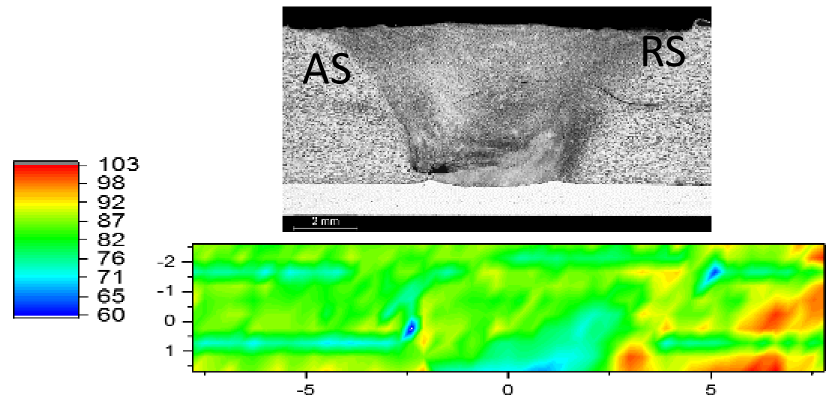


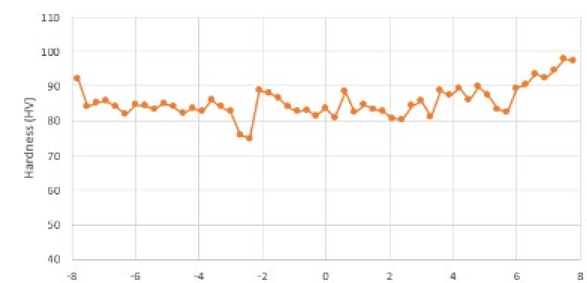
Load bearing capacity:**581±30N/m**

- Pin length has a direct influence in material upturn/ hooking on the retreating side. A 3.1mm long pin resulted in higher load bearing capacity compared to a tool with PL= 3.4mm. (Retreating side loaded top sheet)

Peel strength asymmetry [retreating side loaded is better]

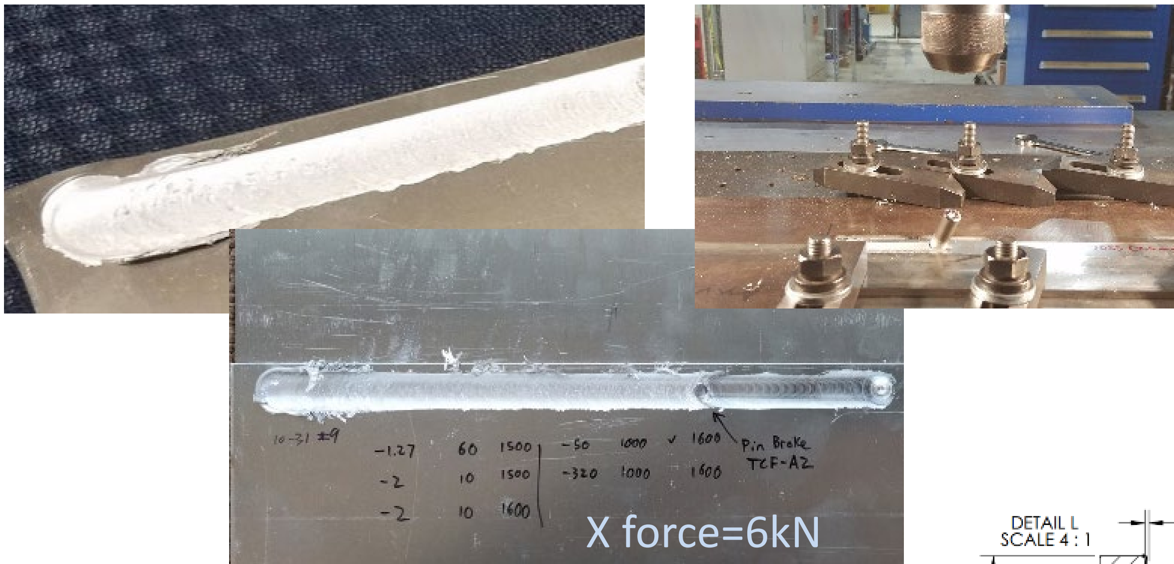




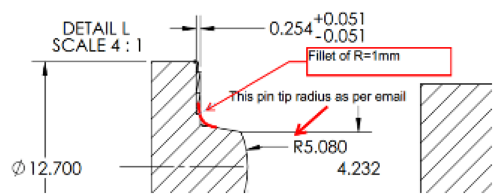


While top sheet loaded on advancing samples are performing better in lap shear, Peel test data indicates opposite effect.

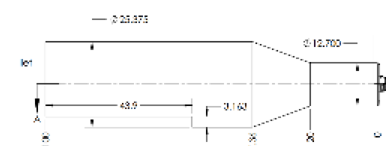
3 sheet 7055 trials: Tool failures



Tool pin fracture takes place near the base of pin at thread root.



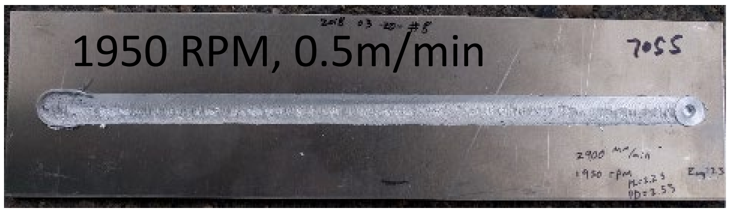
Solution approach

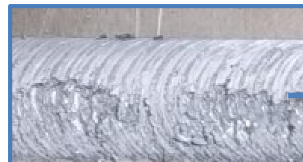


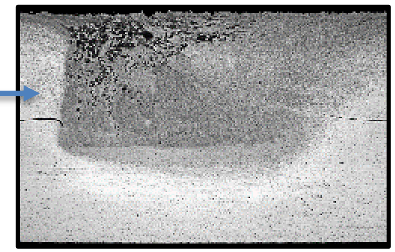
1) Change design of the shank and pin to minimize stress concentration.
2) Material change from H13 to MP159

Temperature tradeoff: A delicate dance

Pacific Northwest NATIONAL LABORATORY




Possible surface Incipient melting in 7xxx series




Smooth surface

Potential solution:

<u>Decrease shoulder feature.</u>

Aggressive

Smoother feature

- Weld crown surface is sensitive to welding parameters.
- With higher shoulder heating (caused by greater RPM needed for higher welding speed, likely incipient melting is observed.
- Lower shoulder temperature: better surface but tool forces increase.

Welding fixture designs for Demo parts.